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# The Steam Laboratory of the IMNSSA: A Set of Tools in the Service of the French Navy

**PhD. Anne-Virginie Desruelle, Tech. Bruno Schmid, Col. Alain Montmayer**

Institut de Médecine Navale du Service de Santé des Armées

BP 610

F-83800 Toulon Naval

France

## Summary

Accidental exposure to hot water steam is a potential risk in the French Navy, and particularly on nuclear submarines or ships. Direct human exposure to this extreme environment during an accident leads to death in a short time.

In order to protect the crew members of the French Navy, a laboratory was created at the Institut de Médecine Navale du Service de Santé des Armées (IMNSSA). A set of tools was developed to study the effects of exposures to hot water steam atmospheres on human physiology and on protective capacities of textiles fabrics and equipments.

## Introduction

Accidental exposure to hot water steam is a potential hazard in the French Navy and particularly on nuclear submarines or ships (Etienne et al., 1999).

To study the effect of human exposure to accidental steam atmosphere and in order to protect the crew members of the French Navy, a steam laboratory was created at the Institut de Médecine Navale du Service de Santé des Armées (IMNSSA). To carry out this study, a set of tools was developed: a testing device which can generate steam jets or steam atmosphere, a thermal copper manikin, a steam climatic chamber and a computer model of human thermal physiology.

The testing device allows to quantify the protective capacities of textile fabrics under steam stresses. The thermal manikin and the steam climatic chamber allow to evaluate protective capacities of equipments. The model allows to estimate the thermal strain due to the equipment and the environment.

## Description of the materials of the laboratory

### *The testing device*

The testing device can be used under two configurations : steam jet or steam atmosphere (Figure 1). It is composed by:

- a steam generator (Sano clav Wolf, Bioblock Scientific, France) which has a maximal inside temperature of 142°C, corresponding to a pressure of 3 bars. Steam is coming out from a copper tube (11 cm longer and 5 mm internal diameter) oriented toward the center of the measuring cell.
- a sample support composed by a PVC double frame in which the sample is inserted. The two sides of the frame present a circular window corresponding to the measuring cell diameter. The part opposed to steam is equipped to attach the measuring cell and to make a close contact between the cell and the internal side of the sample (supposed to face skin).
- a measuring cell (Figure 2) composed of a heat flux sensor (Episensor 025, JBMEurope, France) stuck on a hollow cylindrical box in which water circulates at a regulated temperature of 33°C. The side of the box facing steam (or the internal side of the samples) is made of an external resin layer (to minimise the radial heat flux) over an aluminium plate. The heat flux sensor, imbedded in the resin layer, is stuck on the aluminium plate to facilitate the transfer of the heat to the water. The sensor measures the heat flux and also the temperature of its surface under its external black paint layer.

Under steam jet configuration, the sample support and the measuring cell are fixed on a moving base. Under steam atmosphere configuration, this moving base is replaced by an isolated box in which steam atmosphere is created. In this configuration, the steam injection is made by an electrovalve asserved to a thermal regulator which regulates the box temperature at 80°C. In the two configurations, the measuring cell is

connected to a data logger (DaqBook 216, IOtech, USA) and then to a computer that allows to observe and save the measures (software: Daqview 7.1, IOtech, USA).

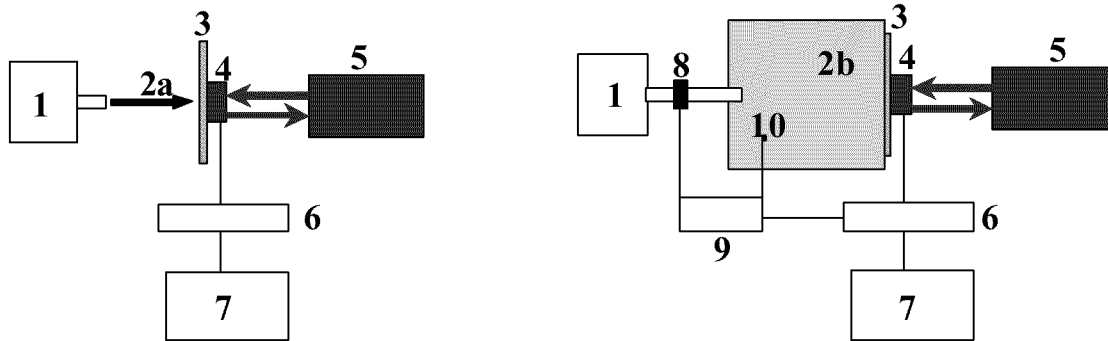


FIGURE 1 : Diagram of the testing device under steam jet (left panel) and steam atmosphere configuration (right panel). 1 : steam generator. 2a : steam jet. 2b : isolated box. 3 : textile sample. 4 : measuring cell. 5 : regulator of the water temperature of the measuring cell. 6 : data logger. 7 : computer. 8 : electrovalve. 9 : thermal regulator. 10 : temperature sensor.

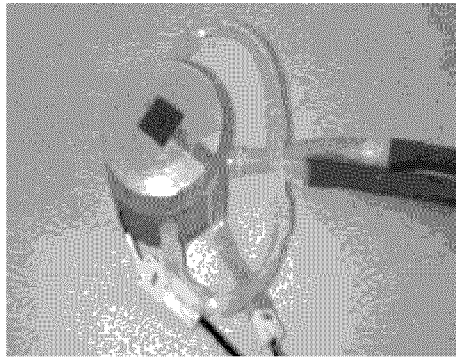


FIGURE 2 : The measuring cell, view of the sight facing steam or the internal side of the sample.

#### *The climatic chamber*

The climatic chamber (7 m<sup>3</sup>) allows to generate a full saturated atmosphere of 80°C. The steam atmosphere is created by an air-conditioning (heating system and humidifier) working in close-circuit. Steam can be rapidly evacuated outside for security reasons.

The thermal conditions inside the chamber are regulated by a computer. Air and dew point temperatures are measured and stored on the same computer. The air temperature can be regulated between the air temperature of the laboratory and 90°C ( $\pm 1^\circ\text{C}$ ) and the dew point one between those of the laboratory and 80°C ( $\pm 1^\circ\text{C}$ ).

#### *The copper thermal manikin*

The thermal manikin is divided in nine separate segments. The surface of the manikin is made of copper sheets and is regulated by water circulated inside copper pipes distributed on the internal face of the sheets (regulated surface: 1.349 m<sup>2</sup>). The inside of the manikin is isolated to limit heat storage and natural convection. This manikin presents two distinctive features compared to the majority of the other thermal manikins. It should be as watertight as possible and be cooled rather than warmed during the tests. The cooling system is composed by a primary input which is divided then in 3 secondary ones : one for the top (head, arms, front and rear trunk) and one for each leg, and then the water is distributed in the different segments. Each segment has a separate water output. The temperature of the primary input is regulated between 20.0 to 40.0°C ( $\pm 0.2^\circ\text{C}$ ), and the temperatures of the each segment are measured. The water flows are measured (Mc Milan Co, USA) and regulated at the output of each segment between 0.06 to 1.00 l.min<sup>-1</sup> ( $\pm 5\%$ ). Thus, total and local heat fluxes are calculated from temperatures and water flows.

### *The computer model of human thermophysiology « Protect »*

« Protect » is a computer model of human thermophysiology created by Dr V Candas (CEPA/CNRS, Strasbourg, France) based on the Stolwijk model (Stolwijk, 1970) to which a model of heat transfer through clothing and a model of heart rate are added.

The input parameters concern the climatic environment (air, radiant temperatures, relative humidity, air velocity and solar heat flux), the clothing and underwear (insulation, evaporative resistance, thickness, percent of body area covered ...), the ventilation inside the garment (temperature and humidity of the air ventilated, distribution of the ventilation on the body surface), the potential human (height, weight) and his activity (metabolism, kind of activity).

The output parameters are temperatures of the garment, underwear and microclimate, internal and skin temperatures, sweat rates, dehydration, skin wettedness, heart rate.

Protect allows to realize scenarios composed of several trials having its own lasting. For each trial, all the input parameters can be changed.

Protect has been validated in warm to slightly hot climates with good agreement with measures (mean  $\pm$  2 SD) but not in steam atmosphere.

### **Testing procedures**

#### *Textile fabrics evaluation on testing device*

Textile samples are exposed three times during ten minutes to four conditions of steam aggression (three conditions of steam jet and one of steam atmosphere). The Ref test corresponds to the exposure of the measuring cell directly to steam aggression, without any sample. During Ref tests, the steam jet conditions lead to average heat flux rates of 43.12 (SD: 0.26), 33.94 (SD: 0.39) and 28.04 (SD: 0.33) kW.m<sup>-2</sup>. During Ref test, the steam atmosphere (80°C, saturated) leads to average heat flux rate of 7.02 (SD: 1.17) kW.m<sup>-2</sup>. Heat flux and surface temperature of the flux sensor are measured throughout the test. Total amount of heat received by the cell over the ten minutes and the ratio between heat fluxes measured with samples and those of the Ref tests are calculated. The samples are classified depending on their physical properties and capacity to limit or modify the heat transfer under steam stress.

#### *Equipments evaluation on manikin*

Garments and equipments are exposed to steam atmosphere in the steam climatic chamber. The thermal manikin is worn with the equipment and placed in the center of the chamber. The climatic conditions are 80°C of air temperature with step increase of humidity to the maximum allowed by the equipment. Due to high level of condensation on the regulated surface of the manikin, the chamber cannot reach saturation when the manikin is in. Thus, humidity is increased by step to the maximum the chamber can reach. And the heat flux value at saturation is extrapolated by exponential regression. The same procedure is applied with garments. For each step, the mean temperature of the surface of each segment of the manikin is regulated at 33°C. Temperatures and water flows are measured for each step over 7 minutes. Local and total heat fluxes are then calculated for each step. And the heat fluxes for saturation are calculated by extrapolation. The equipments are classified depending on their heat fluxes (global and local values).

### **Conclusions**

In order to evaluate textiles and clothing protective capacities standards, the steam laboratory develops specific tools and adapts expert appraisals processes. The laboratory is also destined to study the physiopathology of steam injuries and to practise the crew members likely to be exposed to steam stresses.

### **References**

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